Packet Forwarding and Routing Protocols

Cabrillo College

CIS 81 and CST 311

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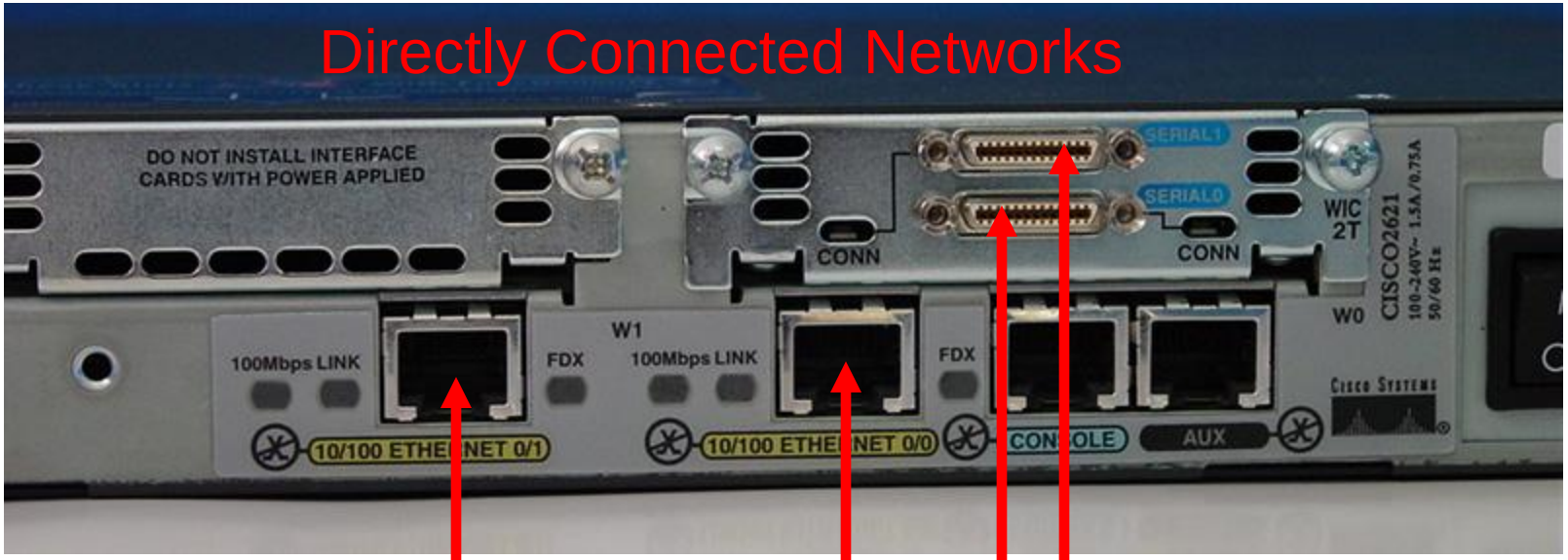
Routers and the Network Layer

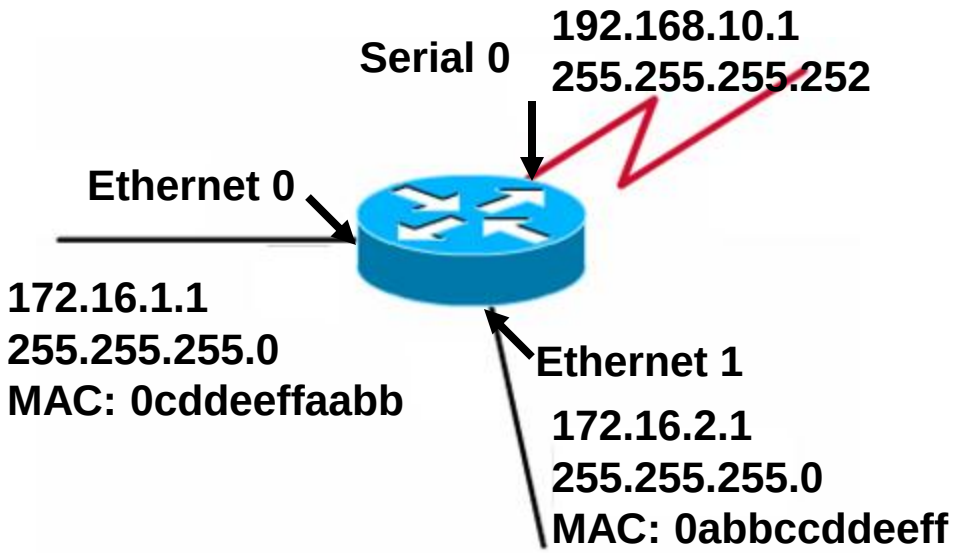
Routers

- Networking devices that make best path decisions (which interface to forward the IP packet) based in Layer 3 IP Destination Address.
- Routers connect multiple networks.



Each interface connects to a different network. Each interface has an IP address/mask for that network.

Routers belong to networks



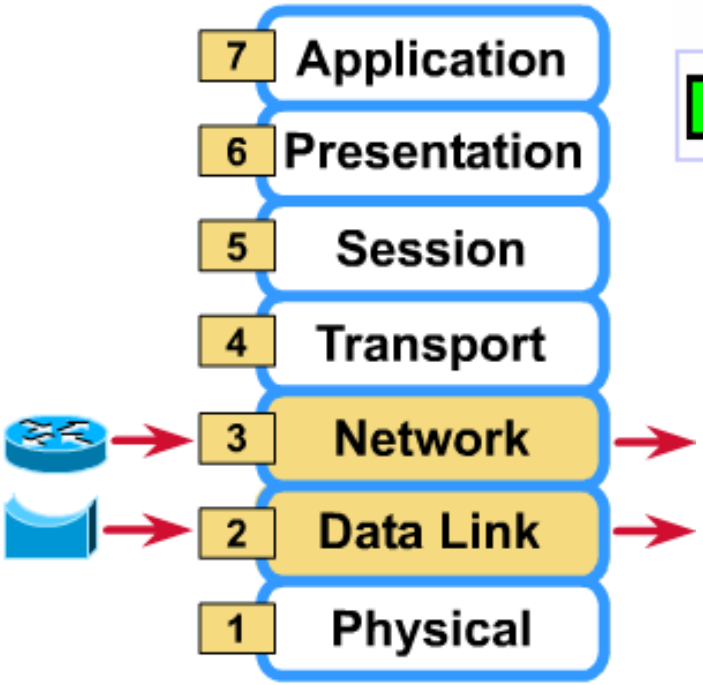
Directly Connected Networks

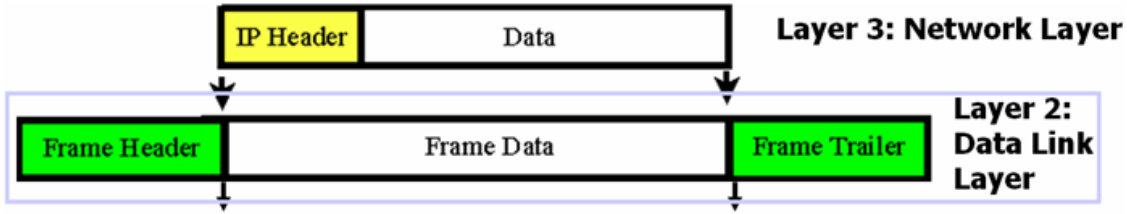
- Router interfaces must be members of different networks.
- Router interfaces participate in the network like other hosts on that network.
- Ethernet interfaces:
  - Have MAC Addresses
  - ARP Tables
  - Participate in the ARP Request and ARP Reply process like other hosts on that network.

Network Layer

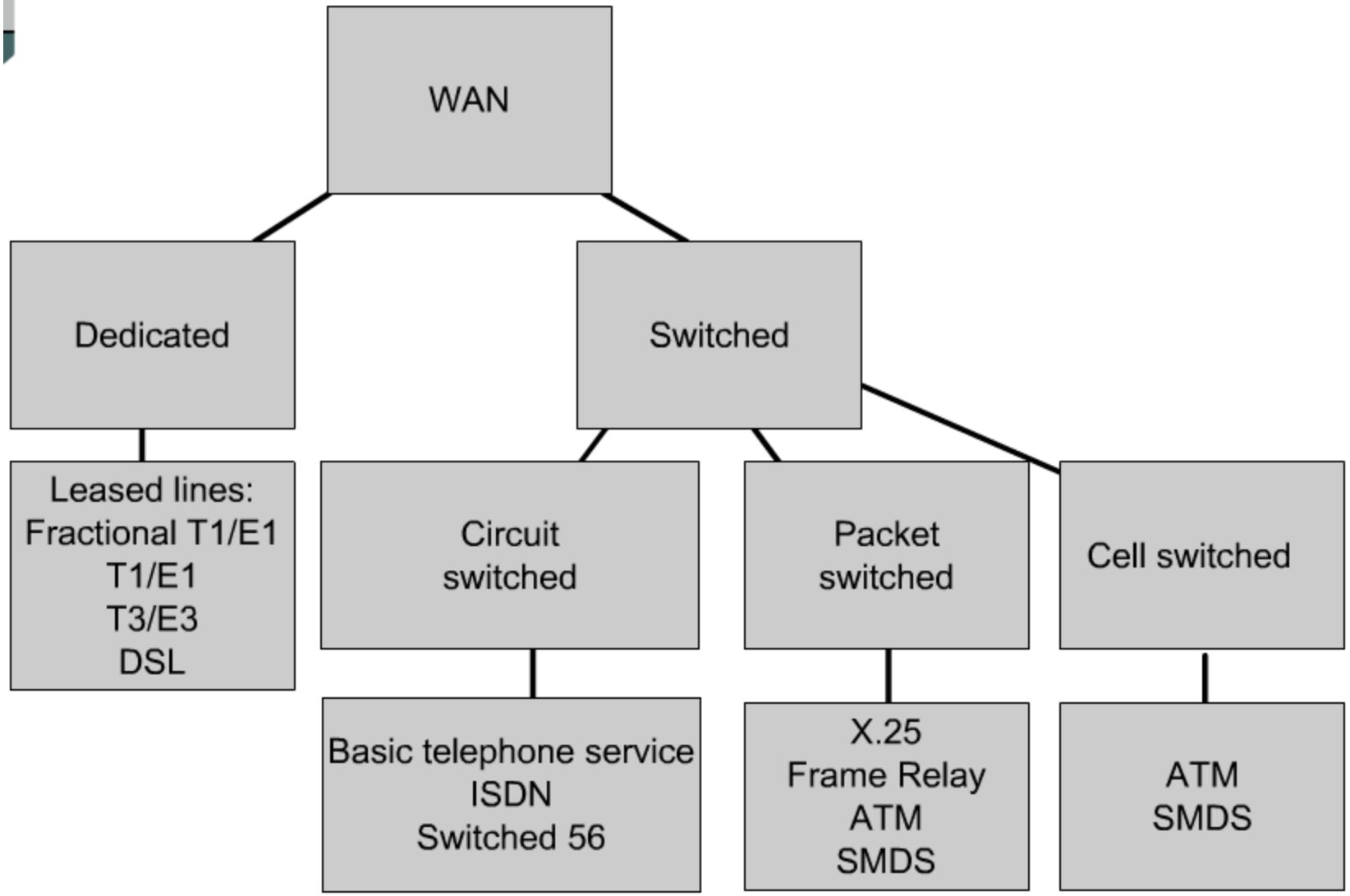
Routers

- Make routing decisions based on Layer 3 information:
  - Destination IP address



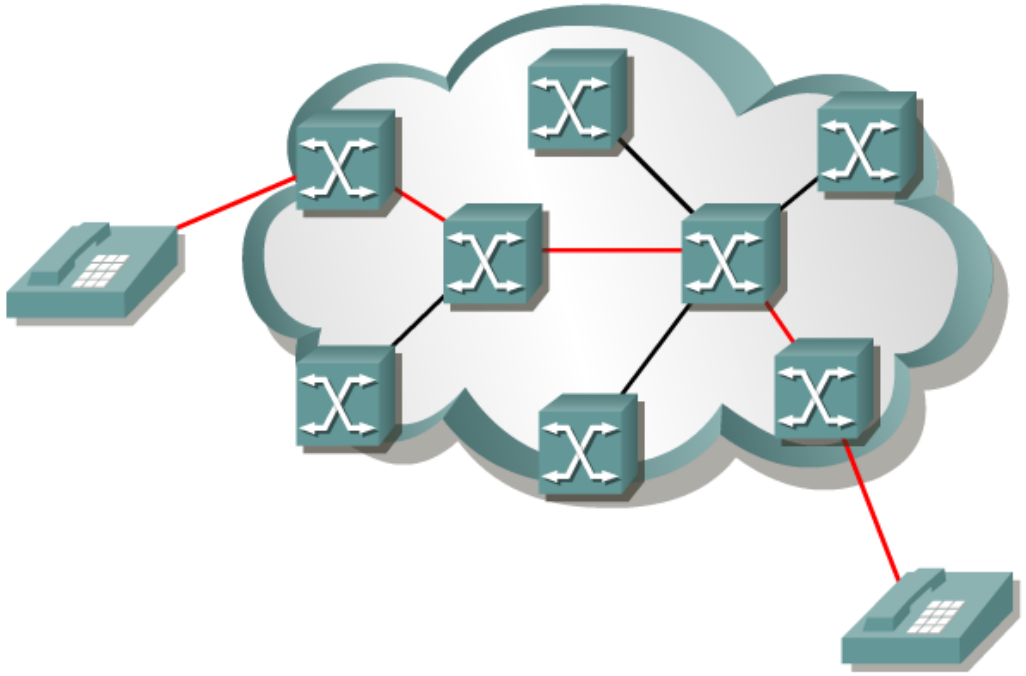


WAN Link Options



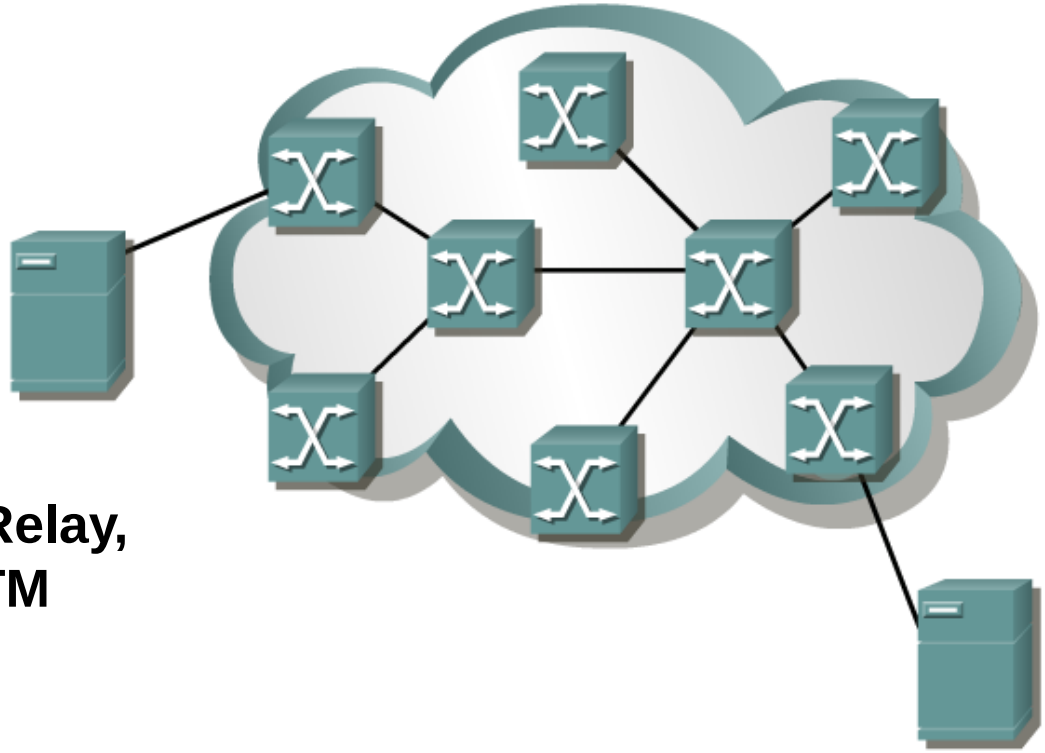
Circuit Switched

- **Circuit Switching:** A form of data communication which establishes a single connection or circuit between source and destination to carry the data stream.
- Like a conventional telephone system.
- When a subscriber makes a telephone call the dialed number is used to set switches in the exchanges along the route of the call so that there is a continuous circuit from the originating caller to that of the called party.



Packet Switching

- **Packet Switching**: A form of data communications which breaks a data stream into small sections, sends them separately by the best available channels and reassembles the original data stream at its destination.
- An alternative is to allocate the capacity to the traffic only when it is needed, and share the available capacity between many users.

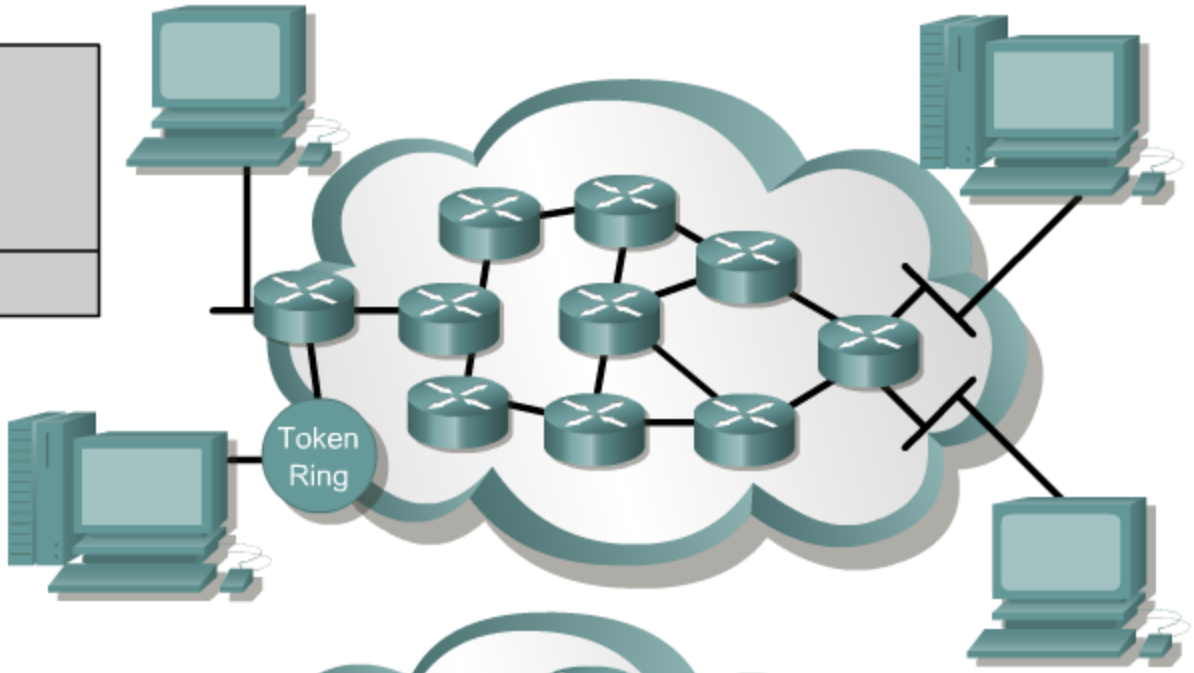


Frame Relay,
X.25, ATM

Routed Protocols vs. Routing Protocols

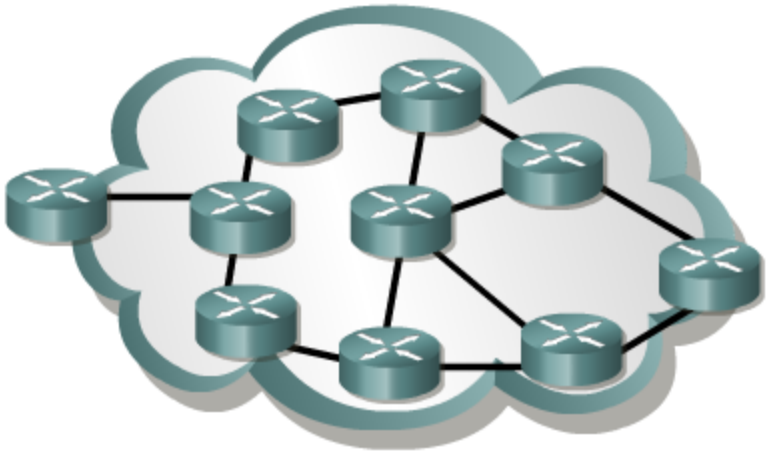
Routed protocol
used between
routers to direct
user traffic

Examples: IP and IPX



Routing protocol
used between
routers to maintain
tables

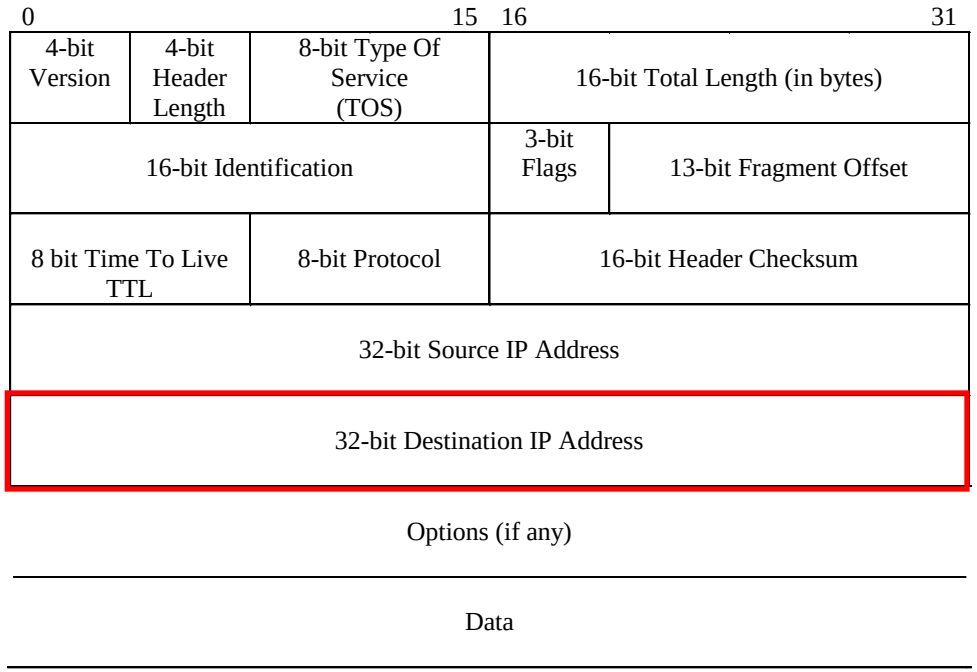
Examples: RIP, IGRP, OSPF



Routed Protocol

- IP is a routed protocol
- A routed protocol is a layer 3 protocol that contains network addressing information.
- This network addressing information is used by routers to determine the which interface, which next router, to forward this packet.

IP Header

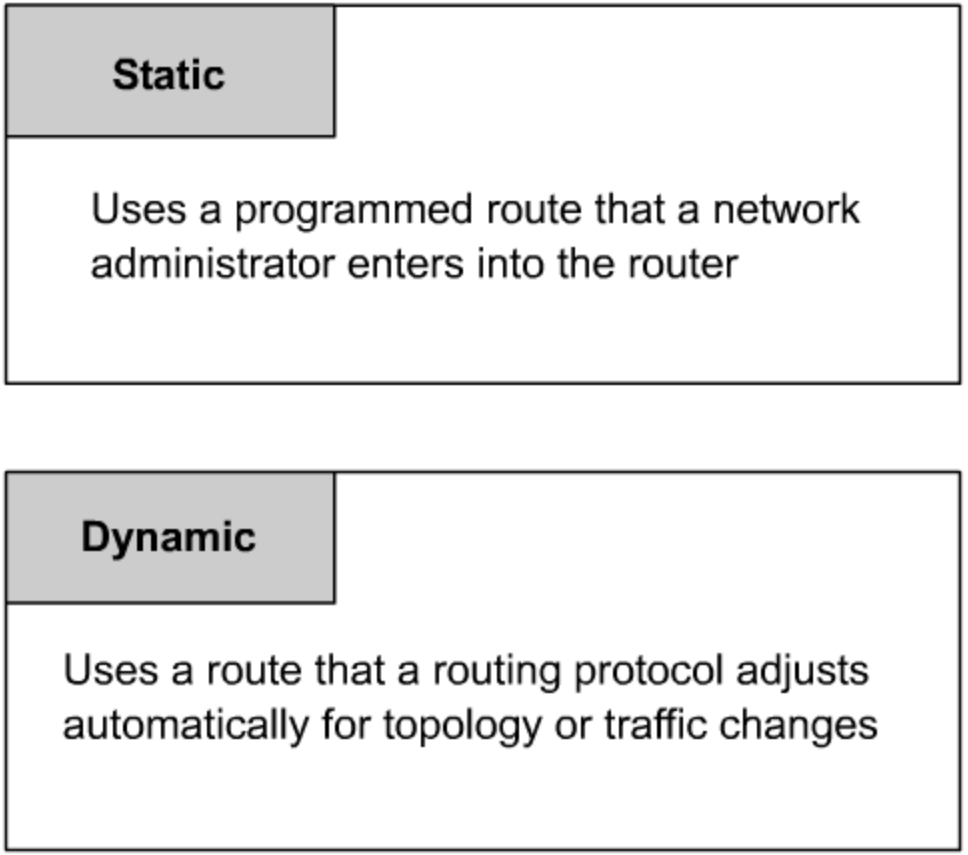


Routing Protocols

- Protocols used by routers to build routing tables.
- Routing tables are used by routers to forward packets.
  - **RIP**
  - **IGRP** and **EIGRP**
  - **OSPF**
  - **IS-IS**
  - **BGP**

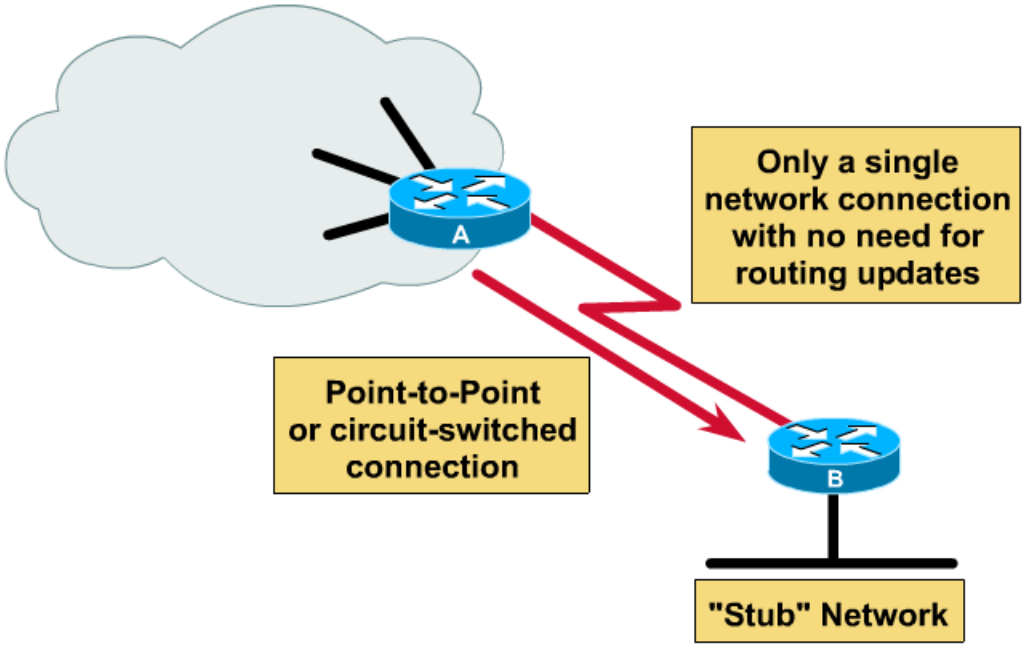
Routing Types

- A router must learn about non-directly connected networks either statically or dynamically.
- **Directly connected networks** are networks that the router is connected to, has an IP address/mask.
- **Non-directly connected networks** are remote networks connected to other routers.



Common uses for Static Routes

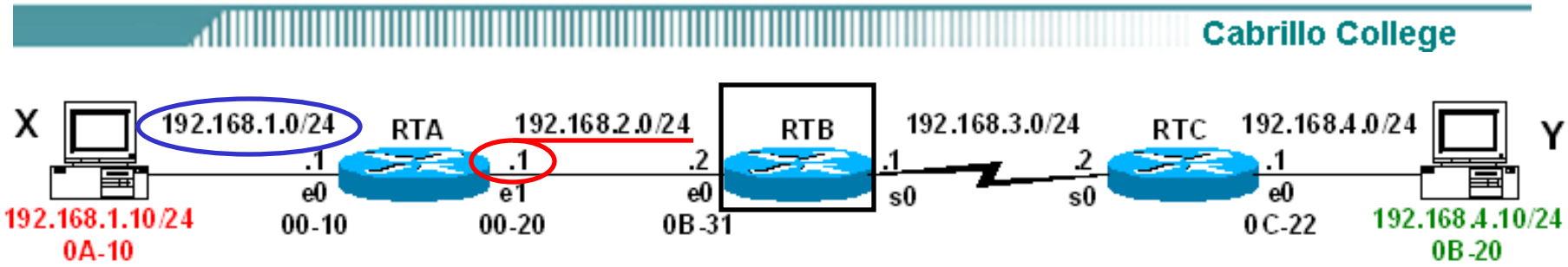
Static Routing Example



Static routes in the real-world

- Soon we will learn about **dynamic routing protocols** (RIP, etc.), where routers can learn automatically about networks, without the manual configuration of static routes.
- **Does this mean that static routes are never used in the real-world?**
- **No!** Static routes are used in conjunction with dynamic routing protocols.
- It is common to use a static route where using a dynamic routing protocols would have disadvantages or where it just not needed.

Static Route Examples



- A router must learn about non-directly connected networks.
- To do this with static routes, Cisco IOS (Internetwork Operating System)

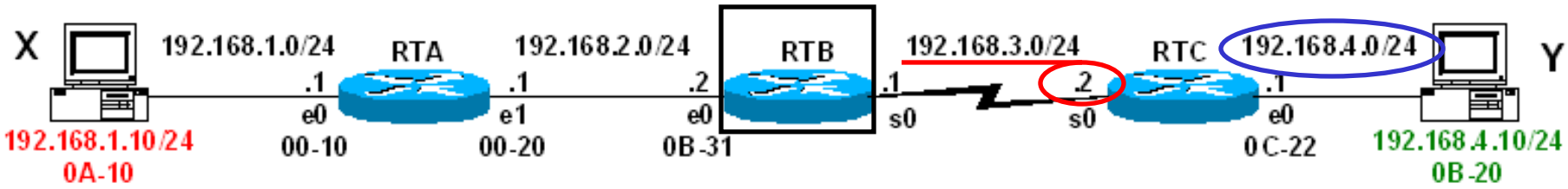
RTB(config)# ip route *network-address mask next-hop-ip-address*

To reach hosts like Host X in the 192.168.1.0/24 network:

RTB(config)# ip route 192.168.1.0 255.255.255.0 192.168.2.1

What would be the static route to reach hosts like Host Y in the 192.168.4.0/24 network?

Static Route Examples

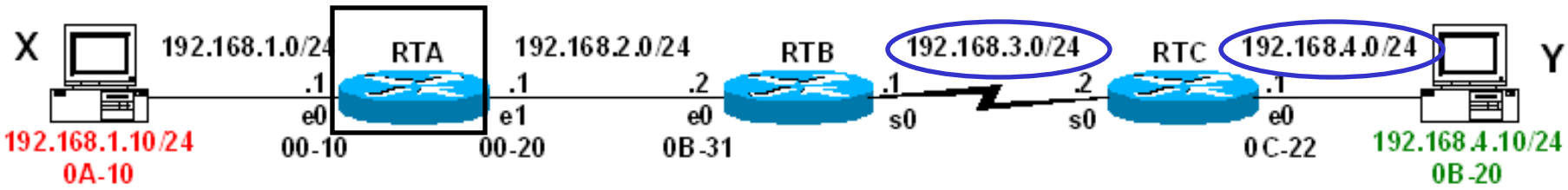


RTB(config)# ip route *network-address mask next-hop-ip-address*

To reach hosts like Host Y in the 192.168.4.0/24 network:

RTB(config)# ip route 192.168.4.0 255.255.255.0 192.168.3.2

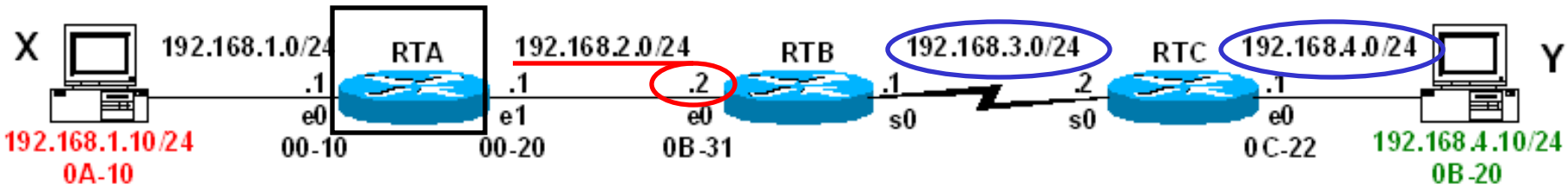
Static Route Examples



What would be the static routes for RTA to reach 192.168.3.0/24 and 192.168.4.0/24 networks?

```
RTA(config)# ip route network-address mask next-hop-ip-address
```

Static Route Examples



RTB(config)# ip route *network-address mask next-hop-ip-address*

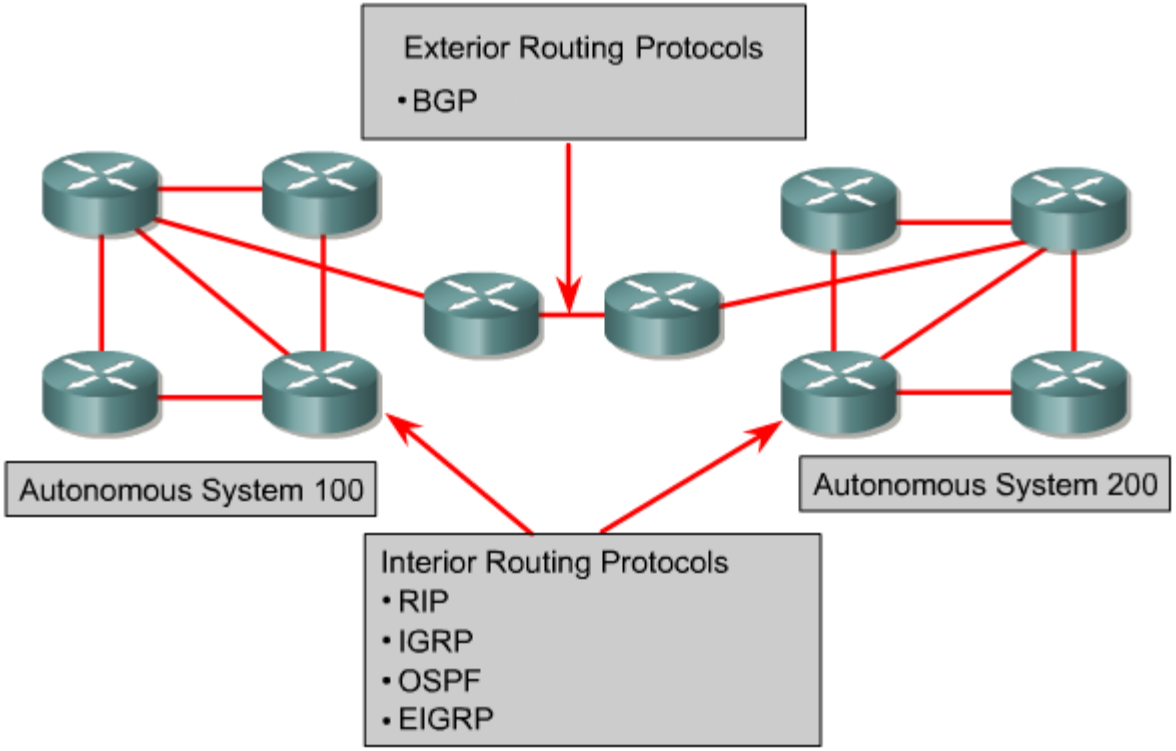
The static routes for RTA to reach 192.168.3.0/24 and 192.168.4.0/24 networks:

RTA(config)# ip route 192.168.3.0 255.255.255.0 192.168.2.2

RTA(config)# ip route 192.168.4.0 255.255.255.0 192.168.2.2

Dynamic Routing Protocols

Routing Protocols



- **RIP** – A distance vector interior routing protocol
- **IGRP** – Cisco's distance vector interior routing protocol
- **OSPF and IS-IS** – A link-state interior routing protocol
- **EIGRP** – Cisco's advanced distance vector interior routing protocol
- **BGP** – A distance vector exterior routing protocol

Routing Protocols – CIS 82 / CST 312

Routing Information Protocol (RIP) was originally specified in RFC 1058.

- It is a **distance vector** routing protocol.
- **Hop count** is used as the metric for path selection.
- If the hop count is **greater than 15, the packet is discarded**.
- Routing updates are broadcast **every 30 seconds**, by default.

Interior Gateway Routing Protocol (IGRP) is a proprietary protocol developed by Cisco.

- It is a **distance vector** routing protocol.
- **Bandwidth, load, delay and reliability** are used to create a composite metric.
- Routing updates are broadcast **every 90 seconds**, by default.

EIGRP is a Cisco proprietary enhanced distance vector routing protocol.

- It is an **enhanced distance vector routing protocol**.
- Uses **unequal-cost and equal-cost** load balancing.
- Uses a combination of distance vector and link-state features.
- Uses **Diffused Update Algorithm (DUAL)** to calculate the shortest path.

Routing Protocols – CIS 82 / CST 312

Open Shortest Path First (OSPF) is a nonproprietary link-state routing protocol.

- It is a **link-state** routing protocol.
- **Open standard** routing protocol described in RFC 2328.
- Uses the **SPF algorithm** to calculate the lowest cost to a destination.
- **Routing updates are flooded** as topology changes occur.

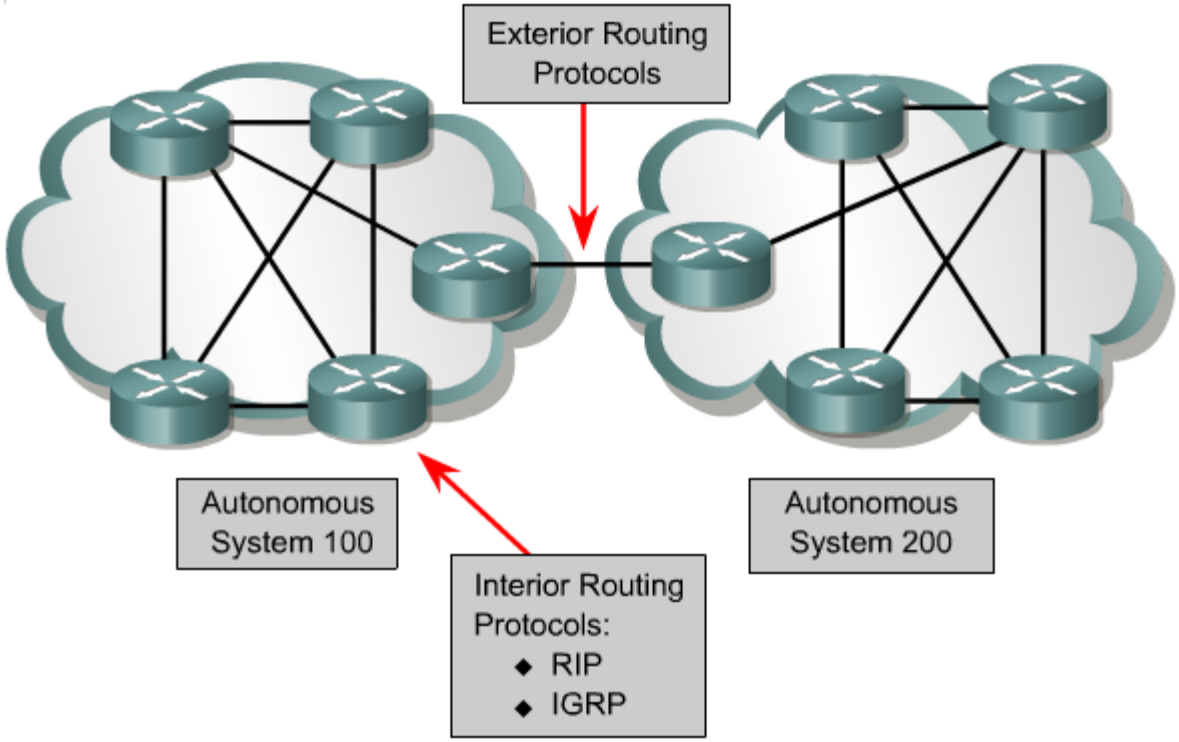
Intermediate System to Intermediate System (IS-IS)

- IS-IS is an Open System Interconnection (OSI) routing protocol originally specified by International Organization for Standardization (ISO) 10589.
- It is a **link-state** routing protocol.

Border Gateway Protocol (BGP) is an exterior routing protocol.

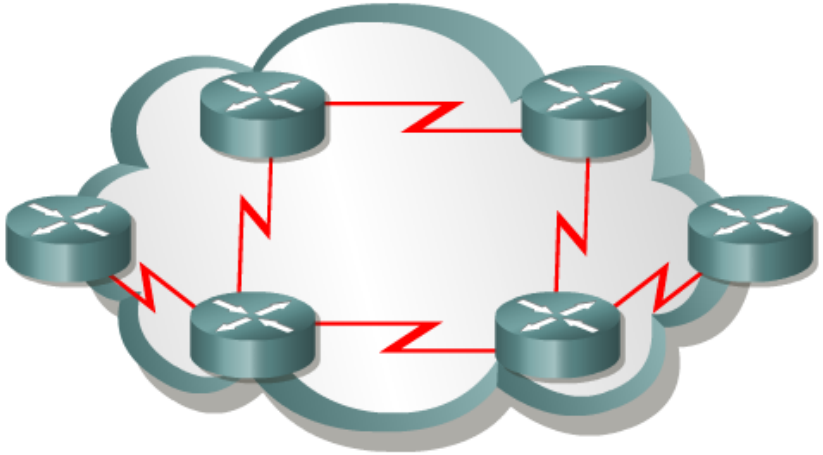
- It is a **distance vector** (or path vector) exterior routing protocol
- Used between **ISPs or ISPs and clients**.
- Used to **route Internet traffic** between autonomous systems.

IGP vs EGP – CIS 82 / CST 312



- Much of this information is too early to discuss.
- Interior routing protocols are designed for use in a network whose parts are under the control of a single organization.
- An exterior routing protocol is designed for use between two different networks that are under the control of two different organizations.

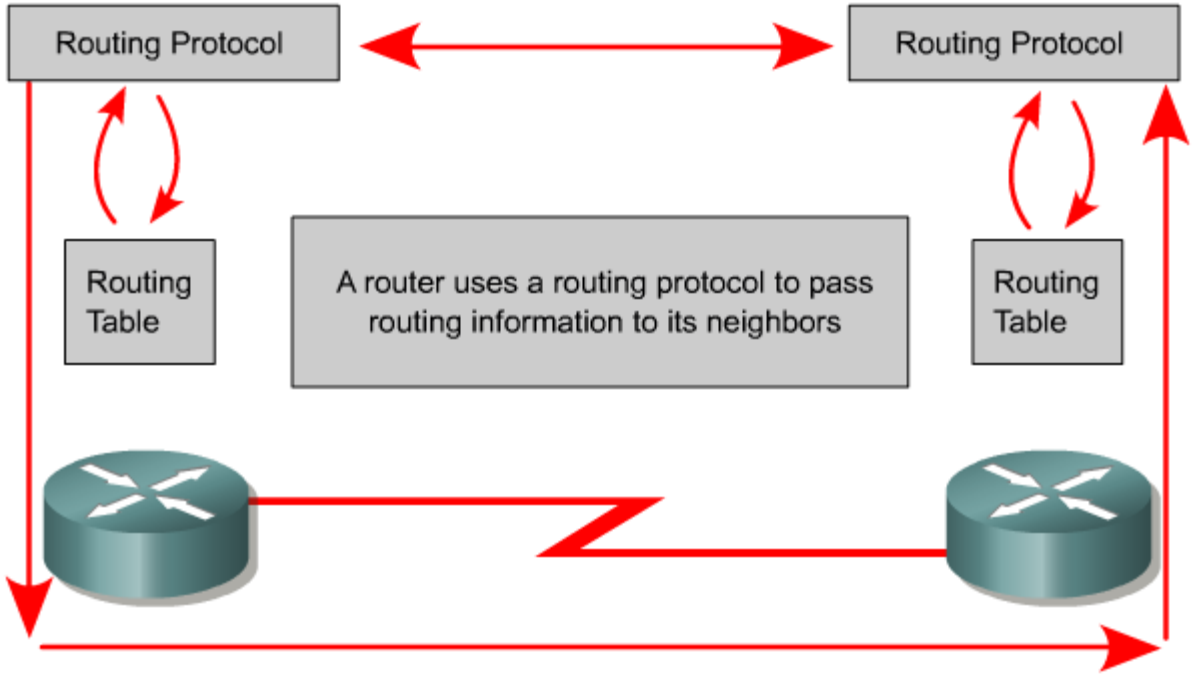
Autonomous Systems – CIS 82 / CST 312



Routers under a common administration

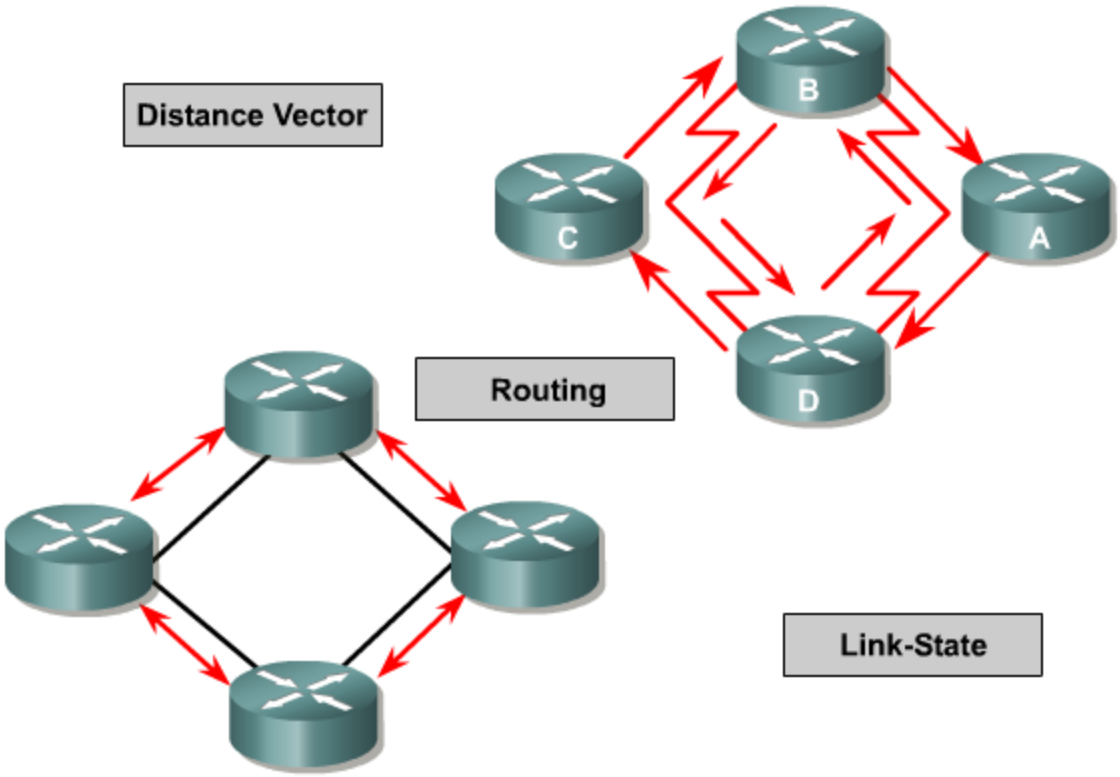
- An autonomous system (AS) is a collection of networks under a common administration sharing a common routing strategy.
- To the outside world, an AS is viewed as a single entity. The AS may be run by one or more operators while presenting a consistent view of routing to the external world.
- The American Registry of Internet Numbers (ARIN), a service provider, or an administrator assigns an identifying number to each AS.

Routing Protocols – CIS 82 / CST 312



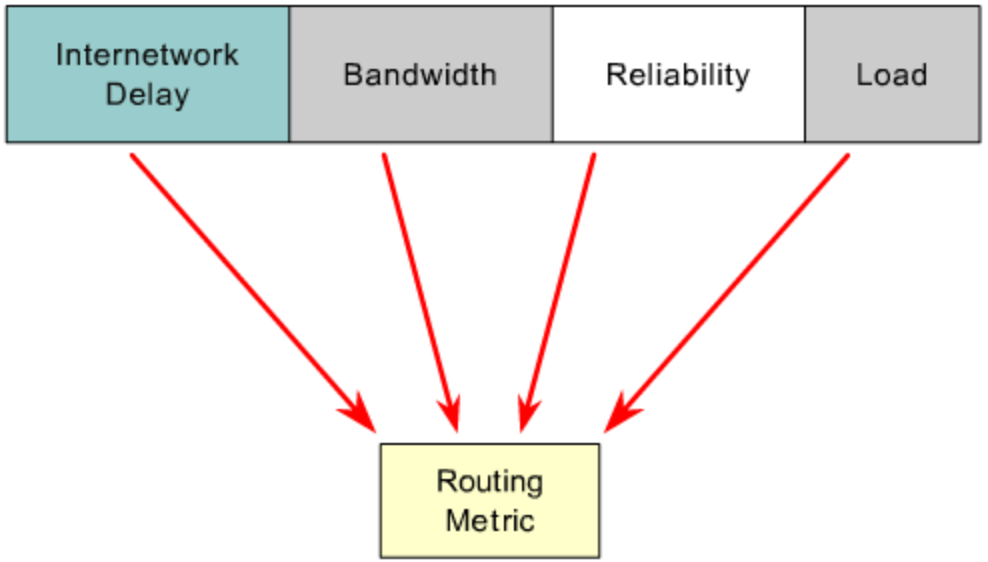
- The goal of a routing protocol is to build and maintain the routing table.
- This table contains the learned networks and associated ports for those networks.
- Routers use routing protocols to manage information received from other routers, information learned from the configuration of its own interfaces, along with manually configured routes.

Types of Routing Protocols



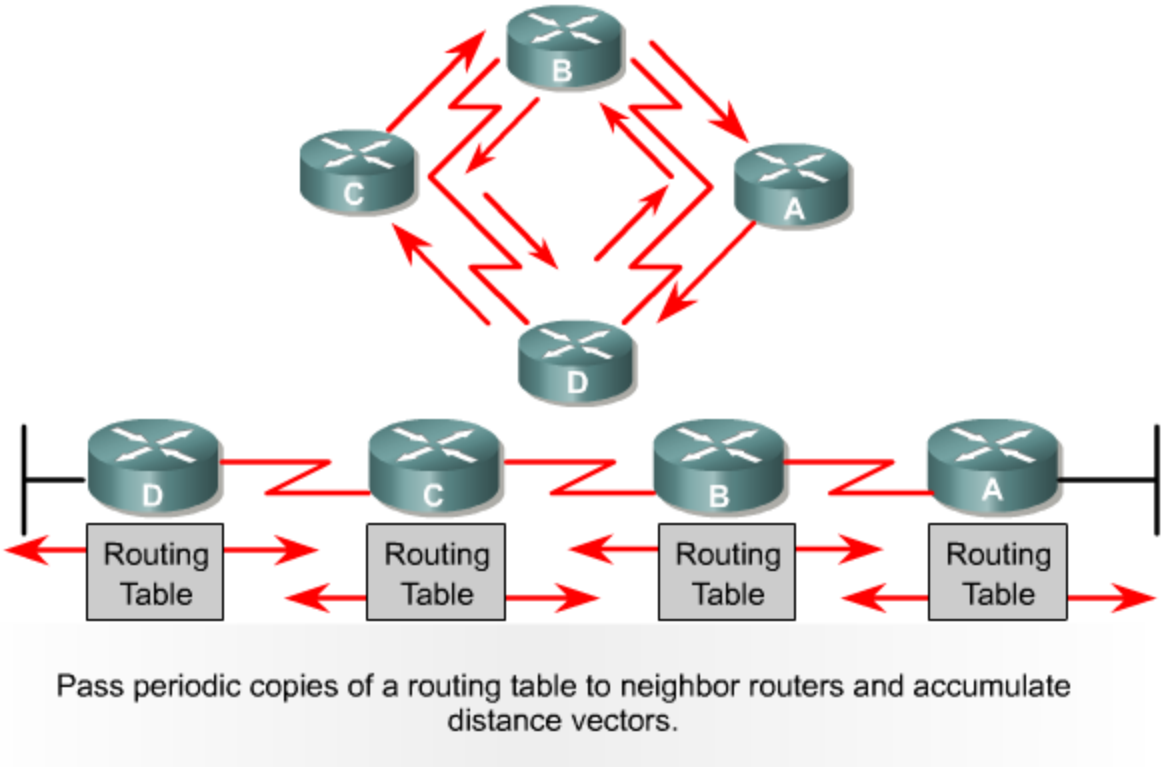
- Distance Vector: RIP, IGRP, EIGRP
- Link State: OSPF, IS-IS
- Path Vector: BGP
- Note: IGRP and EIGRP are Cisco Proprietary

Routing Protocol Metrics (costs)



- RIP – Hop Count
- IGRP and EIGRP – Bandwidth, Delay, Reliability, Load
- Cisco's OSPF – Bandwidth
- IS-IS – Cost
- BGP – Number of AS or policy

Distance Vector Routing Protocols



Pass periodic copies of a routing table to neighbor routers and accumulate distance vectors.

Router B receives information from Router A.

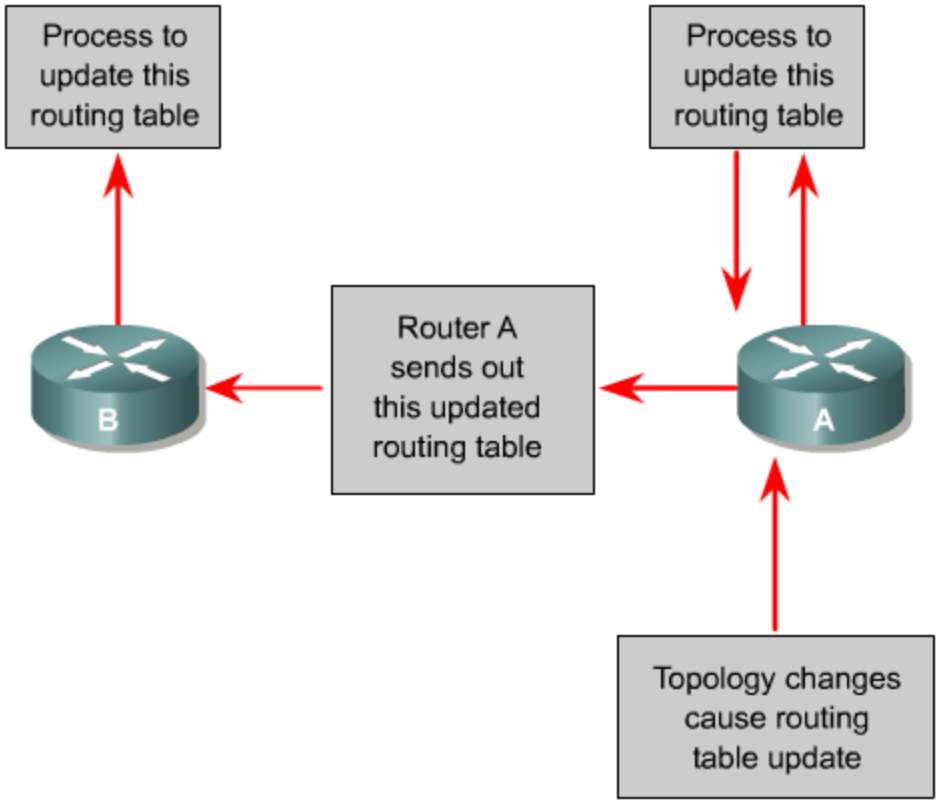
Router B adds a distance vector number (such as a number of hops), which increases the distance vector.

Then Router B passes this new routing table to its other neighbor, Router C.

This same step-by-step process occurs in all directions between neighbor routers.

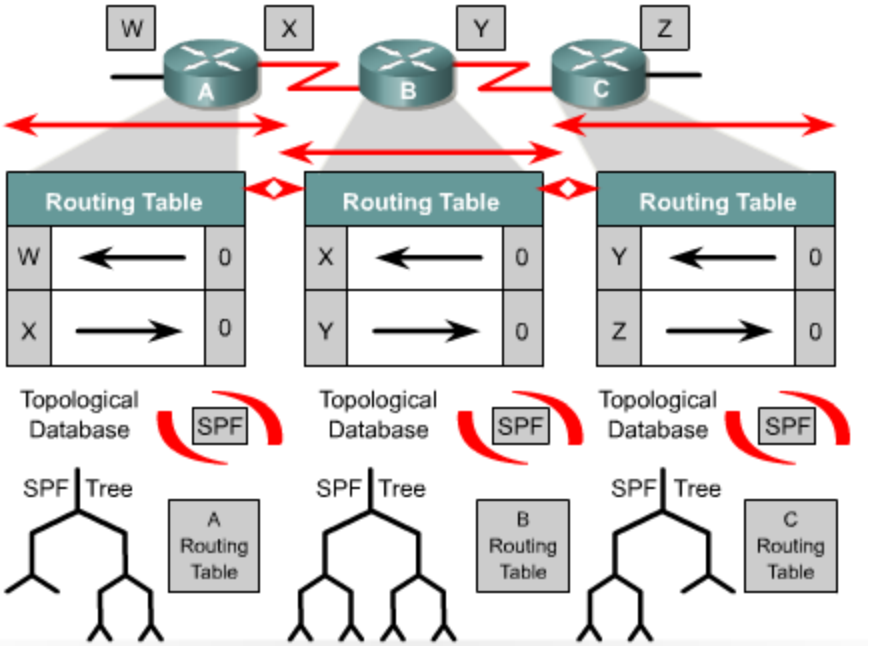
- "Routing by rumor"
- Each router receives a routing table from its directly connected neighbor routers.

Distance Vector Routing Protocols



- Routing table updates occur when the topology changes. As with the network discovery process, topology change updates proceed step-by-step from router to router.
- With some routing protocols routing tables updates happen on a periodic basis.

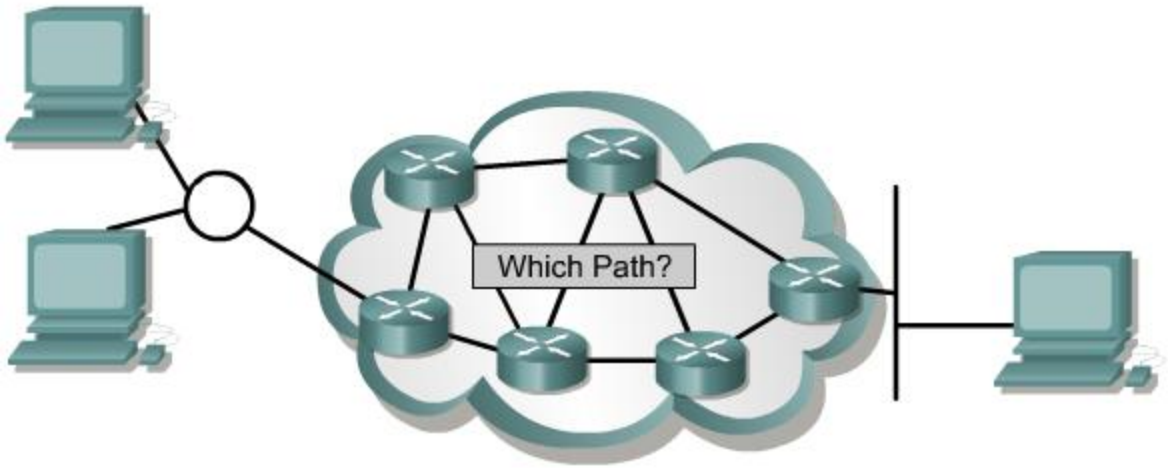
Link State Routing Protocol Operations



Each router has its own topological database on which the SPF algorithm is run.

- We will discuss this in more detail in CIS 82 (CCNA 2) when it will make much more sense.

Path Determination



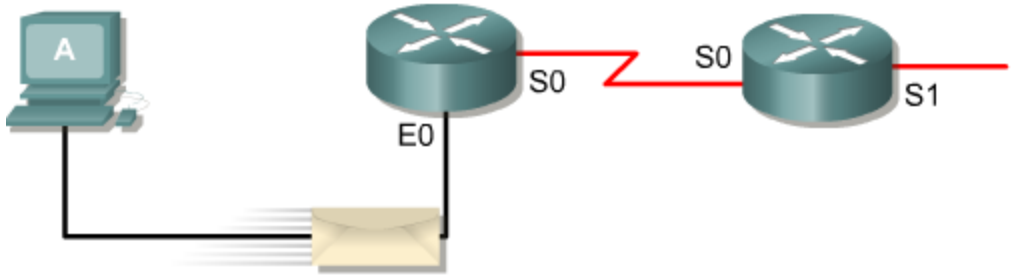
Layer 3 functions to find the best path through the internetwork.

A router determines the path of a packet from one data link to another, using two basic functions:

- A path determination function
- A switching function

Path Determination

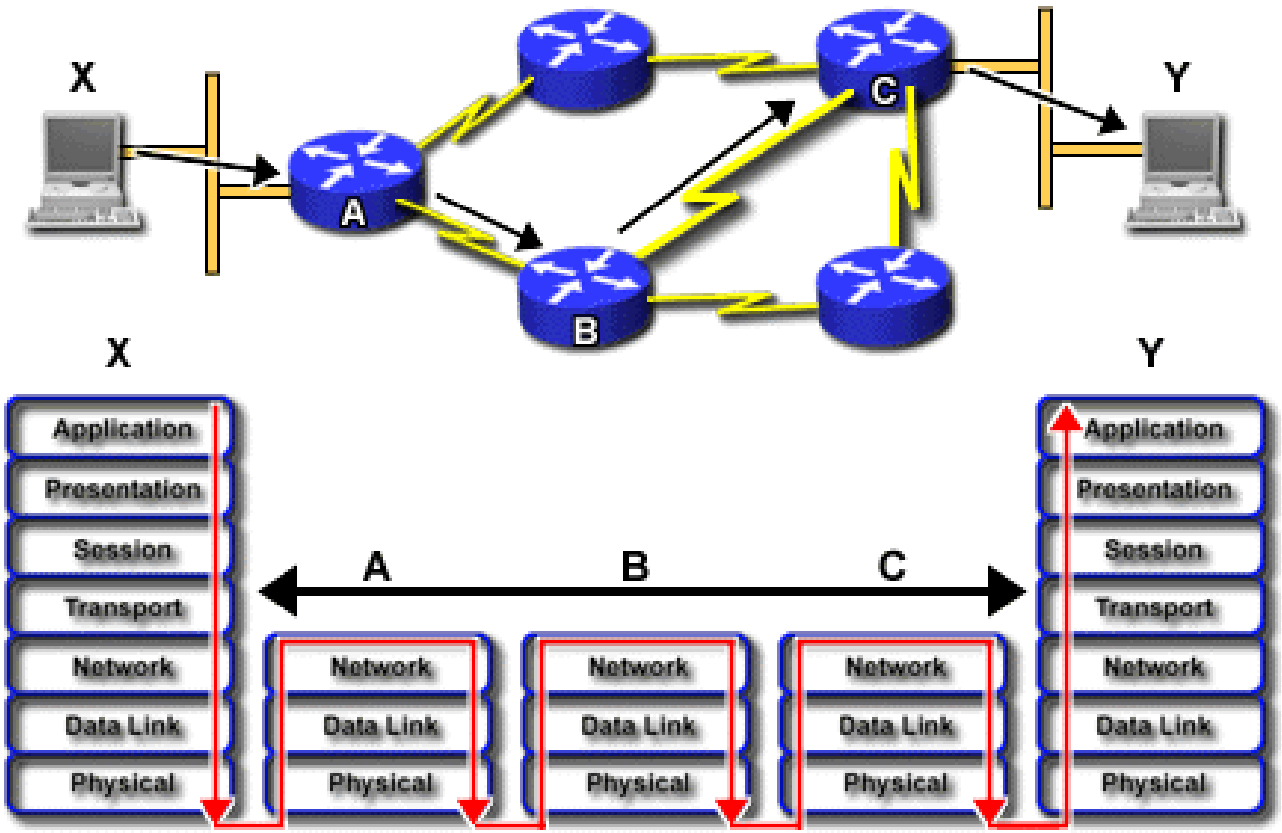
Destination Network	Interface (Next Hop)
172.31.0.0	S0
172.19.0.0	--
192.168.1.0	--
10.0.0.0	E0



- The **switching function** is the internal process used by a router to accept a packet on one interface and forward it to a second interface on the same router.
- A key responsibility of the switching function of the router is to encapsulate packets in the appropriate frame type for the next data link.

End-to-End Routing

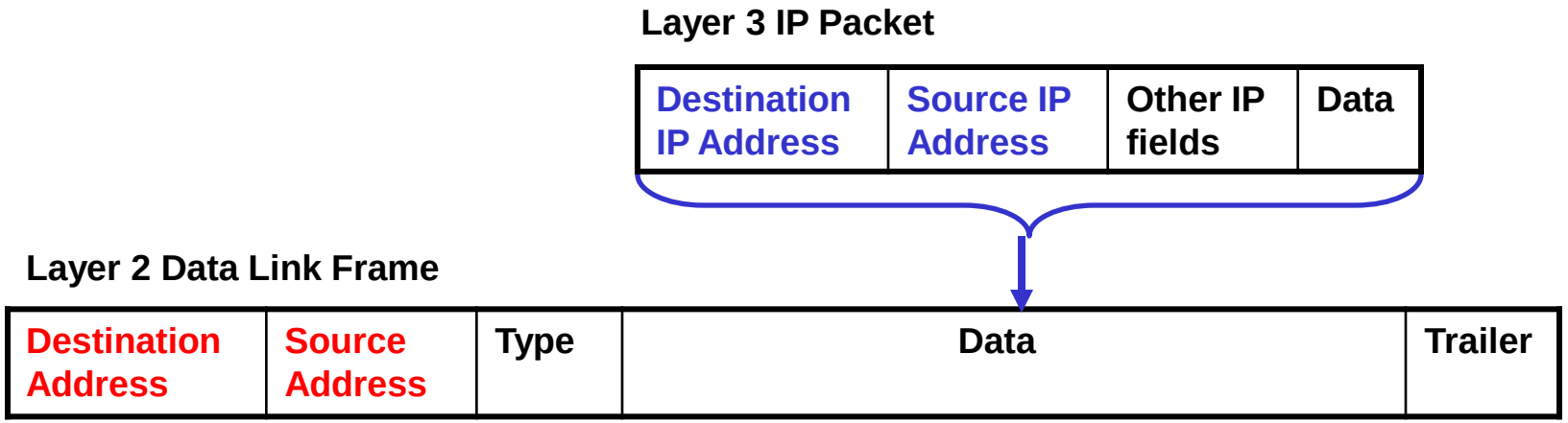
Network-Layer Protocol Operations



- Each router provides its services to suport upper-layer functions

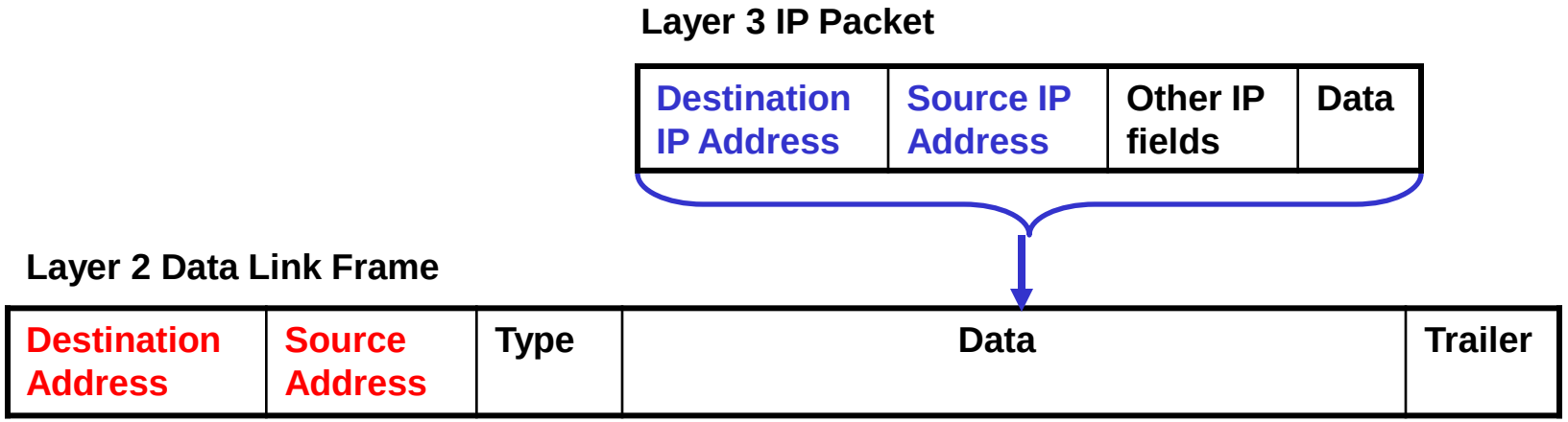
Packet Forwarding

Encapsulation



- Layer 3 packets are encapsulated into Layer 2 frames by the host.
- **Hubs**: Only flood out the Layer 1 bits (repeater)
- **Switches**: Examine only Layer 2 information:
  1. Learn (Source MAC Address)
  2. Forward (Destination MAC Address)
- **Layer 2 frames** can be non-Ethernet frames, such as serial frames:
  - PPP, HDLC, Frame Relay, ATM, ISDN, etc.
  - Point-to-point serial frames (PPP, HDLC) are not multi-access networks and the Destination Address is many times just a layer 2 broadcast address.

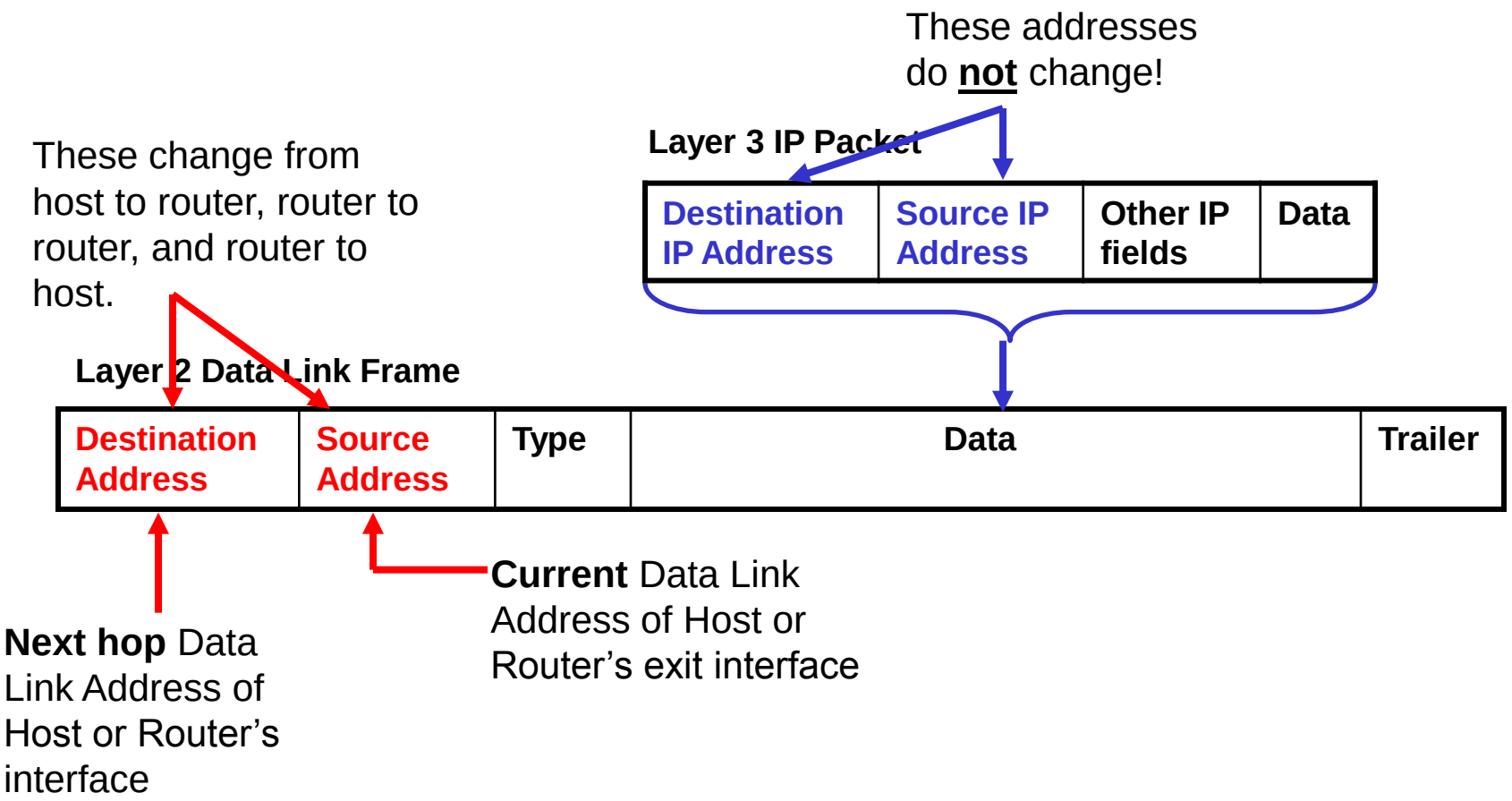
Encapsulation



- **Routers**:
  1. Un-encapsulate Layer 3 packet from Layer 2 frame.
  2. Lookup Layer 3 packet, Destination IP Address, in Routing Table.
  3. Encapsulate Layer 3 packet into new Layer 2 frame and forward out proper (exit) interface.

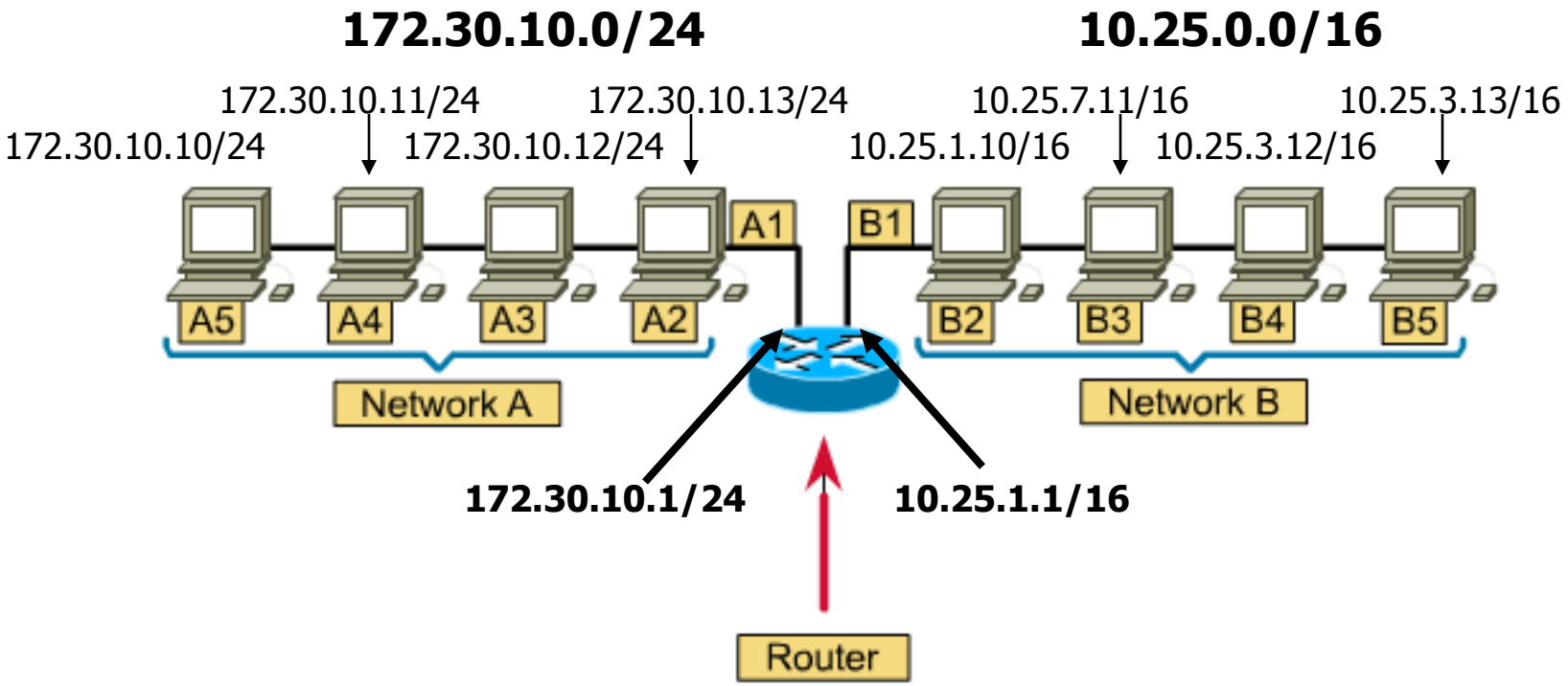
- **Note**: Destination IP Address and Source IP Address are not in their proper order.

Encapsulation



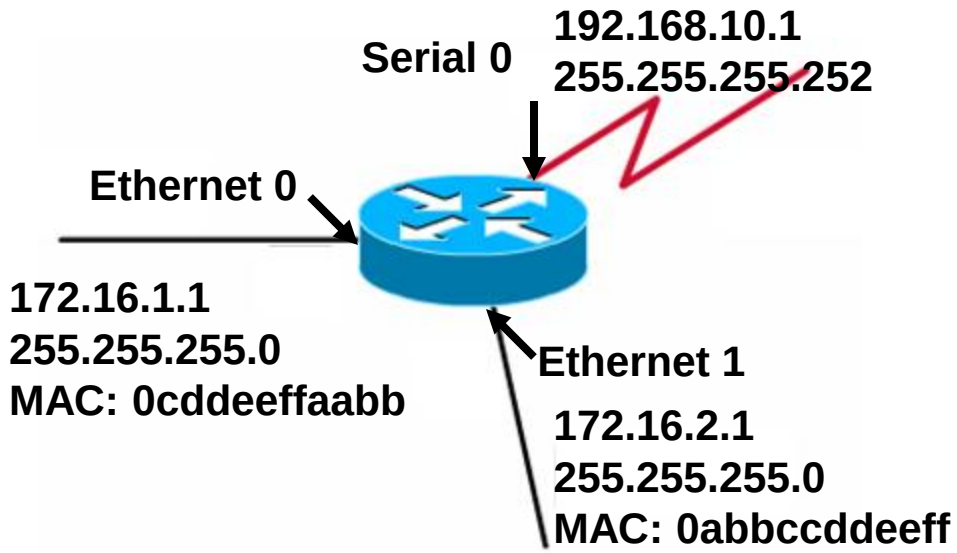
- **Note**: The only time Destination and Source IP Addresses change is with NAT/PAT. The only device that is aware of the change is the device doing the NAT, but for all intensive purposes the rule remains the same, IP Addresses do NOT change.

A router interface is a host on that network



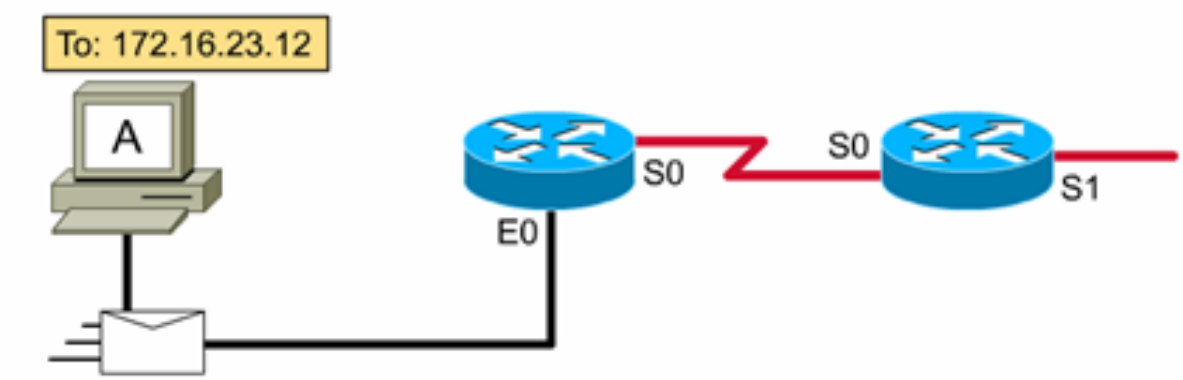
- Since the interface where the router connects to a network is considered to be part of that network.
- Router interfaces have an IP Address and Subnet Mask which makes them a host on the network they are attached.
- Router interfaces must belong to separate networks!

Routers belong to networks



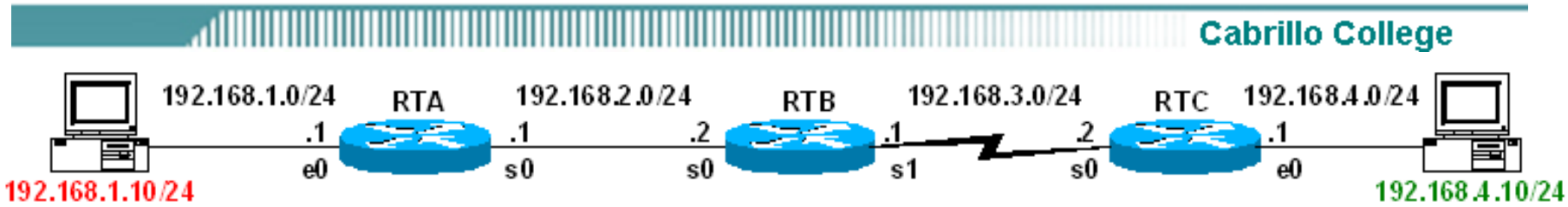
- Router interfaces must be members of different networks.
- Router interfaces participate in the network like other hosts on that network.
- Ethernet interfaces:
  - Have MAC Addresses
  - ARP Tables
  - Participate in the ARP Request and ARP Reply process like other hosts on that network.

Router's Routing Table



- The network layer provides best-effort end-to-end packet delivery across interconnected networks.
- Routers examine the Destination IP Address of a packet to determine where to send the packet next.
- After the router determines which path to use, it proceeds with forwarding the packet.
- It takes the packet that it accepted on one interface and forwards it to another interface or port that reflects the best path to the packet's destination.
- Much more information in the presentation on "The Routing Table Structure" (CIS 82 and CST 311)

Packet Forwarding

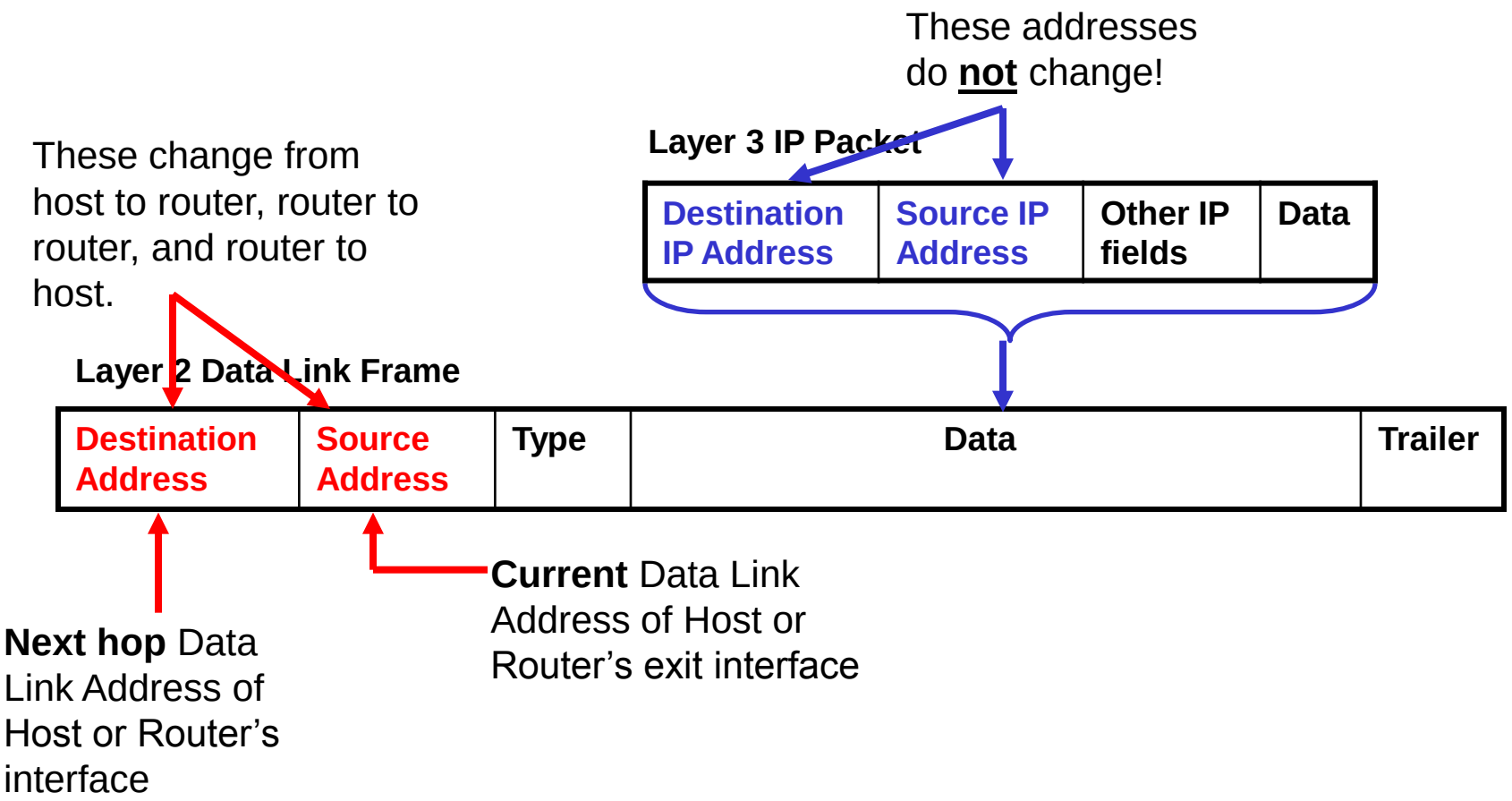


Packet Forwarding

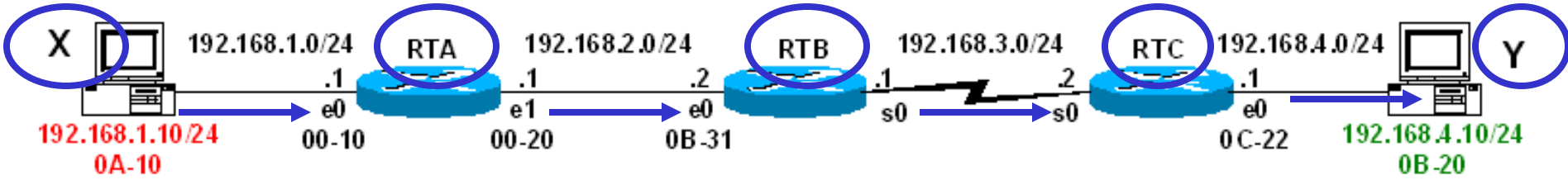
- Host X has a packet(s) to send to Host Y
- A router generally relays a packet from one data link to another, using two basic functions:
  1. a path determination function - **Routing**
  2. a switching function – **Packet Forwarding**

- Let's go through all of the stages these routers use to route and switch this packet.
- **Note**: Data link addresses have been abbreviated.

Remember: Encapsulation



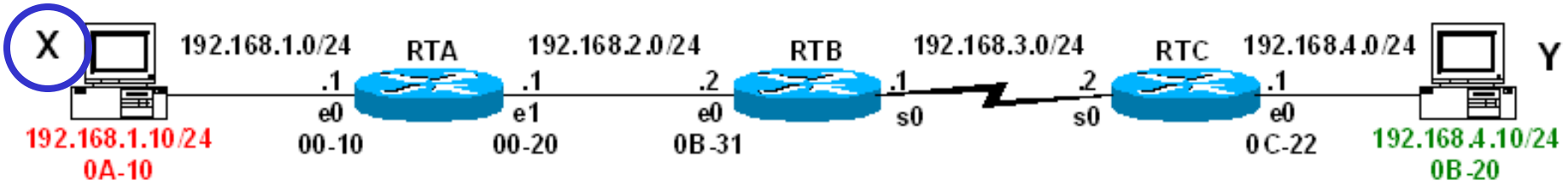
- **Now, let's do an example…**



Layer 2 Data Link Frame **Layer 3 IP Packet**

Dest. MAC 0B-20	Source MAC 0C-22	Type 800	Dest. IP 192.168.4.10	Source IP 192.168.1.10	IP fields	Data	Trailer

- This is just a summary.
- The **details will be shown next!**
- **Now for the details…**

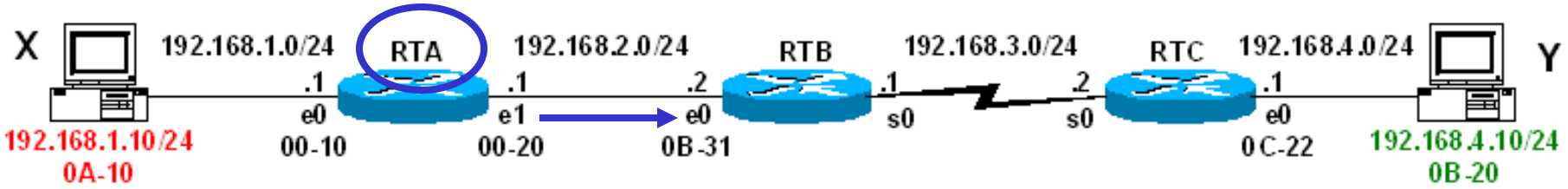


Layer 2 Data Link Frame **Layer 3 IP Packet**

Dest. MAC 00-10	Source MAC 0A-10	Type 800	Dest. IP 192.168.4.10	Source IP 192.168.1.10	IP fields	Data	Trailer

From Host X to Router RTA

- Host X begins by encapsulating the IP packet into a data link frame (in this case Ethernet) with RTA's Ethernet 0 interface's MAC address as the data link destination address.
- How does Host X know to forward to packet to RTA and not directly to Host Y?
  - IP Source and IP Destination Addresses are on different networks
- How does Host X know or get RTA's Ethernet address?
  - Checks ARP Table for Default Gateway IP Address and associated MAC Address.
- What if it there is not an entry in the ARP Table?
  - Host X sends an ARP Request and RTA sends an ARP Reply



Layer 2 Data Link Frame **Layer 3 IP Packet**

Dest. MAC 0B-31	Source MAC 0A-10	Type 800	Dest. IP 192.168.4.10	Source IP 192.168.1.10	IP fields	Data	Trailer

RTA ARP Cache

IP Address	MAC Address
192.168.2.2	0B-31

RTA Routing Table

Network	Hops	Next-hop-ip	Exit-interface
192.168.1.0/24	0	Dir.Conn.	e0
192.168.2.0/24	0	Dir.Conn	e1
192.168.3.0/24	1	192.168.2.2	e1
192.168.4.0/24	2	192.168.2.2	e1

RTA

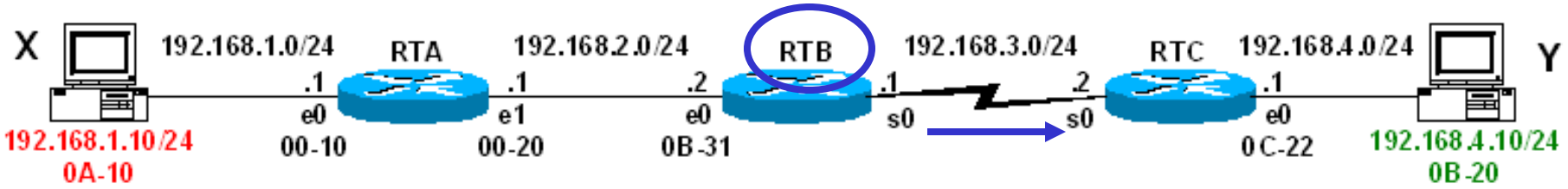
1. RTA examines Destination MAC address, which matches the E0 MAC address, so it copies in the frame.
2. RTA sees the Type field is 0x800, IP packet in the data field, a packet which needs to be routed.
3. RTA strips off the Ethernet frame.

RTA looks up the **Destination IP Address** in its routing table.

- 192.168.4.0/24 has next-hop-ip address of 192.168.2.2 and an exit-interface of e1.
- Since the exit interface is on an Ethernet network, RTA must resolve the next-hop-ip address with a destination MAC address.

4. RTA looks up the next-hop-ip address of 192.168.2.2 in its ARP cache.

- If the entry was not in the ARP cache, the RTA would need to send an ARP request out e1. RTB would send back an ARP reply, so RTA can update its ARP cache with an entry for 192.168.2.2. 5. Packet is encapsulated into a new data link (Ethernet) frame.



Layer 2 Data Link Frame **Layer 3 IP Packet**

Dest. MAC	Source MAC	Type	Dest. IP	Source IP	IP fields	Data	Trailer
0B-BE	00-20	800	192.168.4.10	192.168.1.10			

RTB Routing Table

Network	Hops	Next-hop-ip	Exit-interface
192.168.1.0/24	1	192.168.2.1	e0
192.168.2.0/24	0	Dir.Conn	e0
192.168.3.0/24	0	Dir.Conn	s0
192.168.4.0/24	1	192.168.3.2	s0

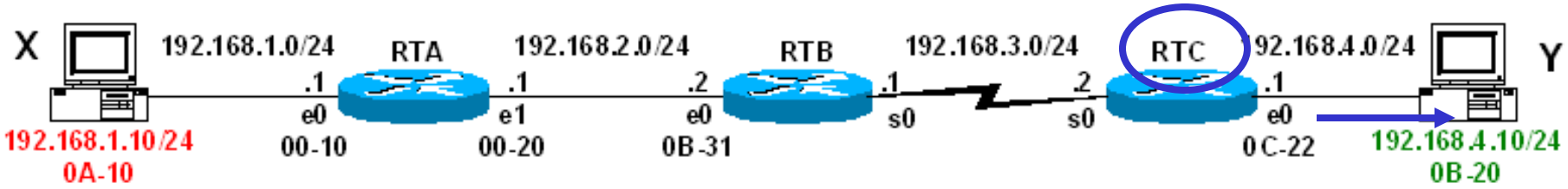
RTB

1. RTB examines Destination MAC address, which matches the E0 MAC address, and copies in the frame.
2. RTB sees Type field, 0x800, IP packet in the data field, a packet which needs to be routed.
3. RTB strips off the Ethernet frame.

RTB looks up the **Destination IP Address** in its routing table.

- 192.168.4.0/24 has next-hop-ip address of 192.168.3.2 and an exit-interface of Serial0.
- Since the exit interface is **not** an Ethernet network, RTB does **not** have to resolve the next-hop-ip address with a destination MAC address.
- When the interface is a **point-to-point serial connection**, (like a pipe), RTB encapsulates the IP packet into the proper data link frame, using the proper serial encapsulation (HDLC, PPP, etc.).
- The data link destination address is set to a **broadcast** (there's only one other end of the pipe).

5. Packet is encapsulated into a new data link (serial, PPP) frame and sent out the link.



Layer 2 Data Link Frame **Layer 3 IP Packet**

Dest. MAC 0B-20	Source MAC 0C-22	Type 800	Dest. IP 192.168.4.10	Source IP 192.168.1.10	IP fields	Data	Trailer

RTC ARP Cache

IP Address	MAC Address
192.168.4.10	0B-20

RTC Routing Table

Network	Hops	Next-hop-ip	Exit-interface
192.168.1.0/24	2	192.168.3.1	s0
192.168.2.0/24	1	192.168.3.1	s0
192.168.3.0/24	0	Dir.Conn	s0
192.168.4.0/24	0	Dir.Conn	e0

RTC

1. RTC copies in the data link (serial, PPP) frame.
2. RTC sees the Type field is 0x800, IP packet in the data field, a packet which needs to be routed.
3. RTC strips off the data link, serial, frame.

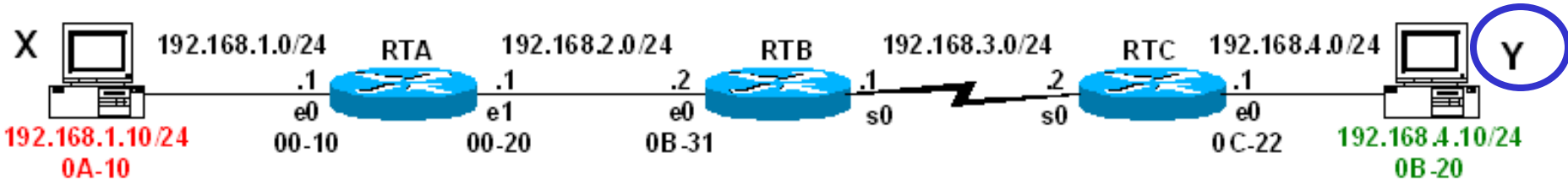
RTC looks up the **Destination IP Address** in its routing table.

- RTC realizes that this Destination IP Address is on the same network as one of its interfaces and it can sent the packet directly to the destination and not another router.
- Since the exit interface is on an directly connected Ethernet network, RTC must resolve the destination ip address with a destination MAC address.

2. RTC looks up the destination ip address of 192.168.4.10 in its ARP cache.

- If the entry was not in the ARP cache, the RTC would need to send an ARP request out e0. Host Y would send back an ARP reply, so RTC can update its ARP cache with an entry for 192.168.4.10.

5. Packet is encapsulated into a new data link (Ethernet) frame and sent out the interface.



Layer 2 Data Link Frame

Dest. MAC	Source MAC	Type	Data	Trailer
0B-20	0C-22	800		

Host Y

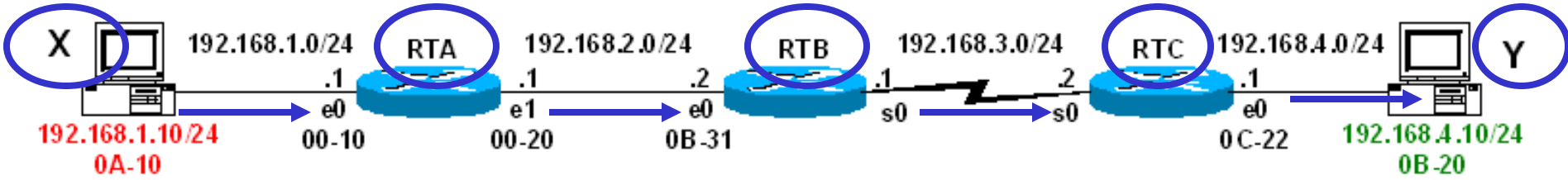
Layer 2: Data Link Frame

1. Host Y examines Destination MAC address, which matches its Ethernet interface MAC address, and copies in the frame.
2. Host Y sees the Type field is 0x800, IP packet in the data field, which needs to be sent to its IP process.
3. Host Y strips off the data link, Ethernet, frame and sends it to its IP process.

Layer 3: IP Packet

4. Host Y's IP process examines the **Destination IP Address** to make sure it matches its own IP Address..
   - If it does not, the packet will be dropped.
5. The packet's protocol field is examined to see where to send the data portion of this IP packet: TCP, UDP or other?

Layer 4: TCP, UDP or other?

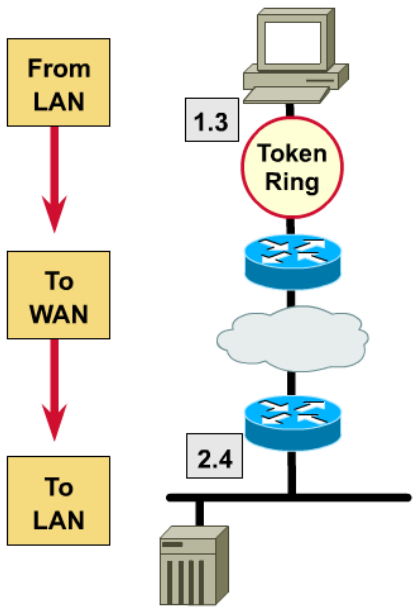


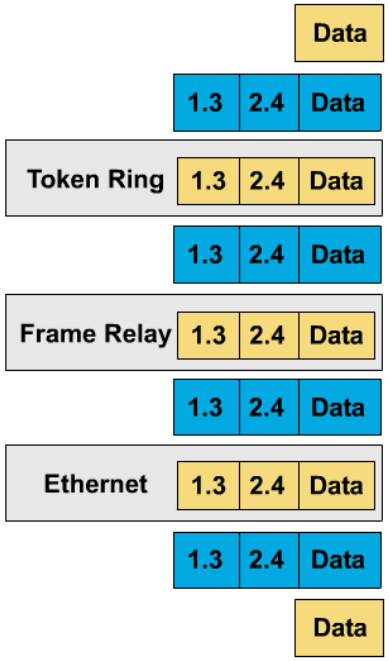
Layer 2 Data Link Frame **Layer 3 IP Packet**

Dest. MAC 0B-20	Source MAC 0C-22	Type 800	Dest. IP 192.168.4.10	Source IP 192.168.1.10	IP fields	Data	Trailer

- The summary once again!

LAN-to-WAN Routing





From Cisco on-line curriculum:

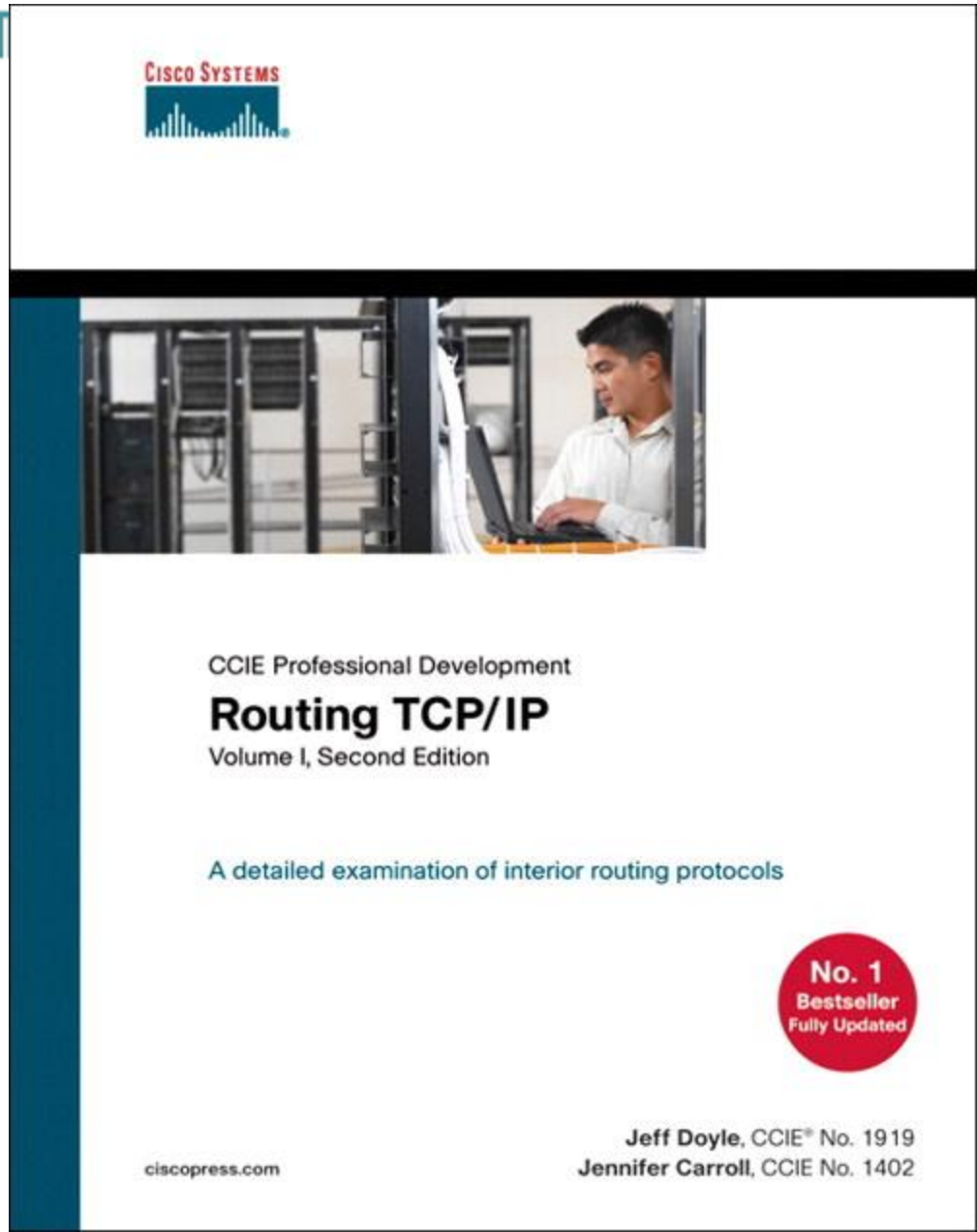
- Routers enable LAN-to-WAN packet flow by keeping the end-to-end source and destination addresses constant while encapsulating the packet in data link frames, as appropriate, for the next hop along the path.

NOTE:

- When the interface is a point-to-point serial connection, the Routing Table process does not even look at the next-hop IP address in the routing table, only the exit-interface.

Book for CIS 82, CIS 83 and CIS 185

- Routing TCP/IP, Volume 1, 2nd Edition
- By Jeff Doyle, Jennifer DeHaven Carroll.
- Published by Cisco Press.
- ISBN: 1587052024
- Published: Oct 19, 2005
- Edition: 2nd.



Packet Forwarding and Routing Protocols

Cabrillo College

CIS 81 and CST 311

Spring 2006

Rick Graziani

Cabrillo College